

Properties of the intermediate type of gamma-ray bursts

I. Horváth*, F. Ryde[†], L.G. Balázs**, Z. Bagoly[‡] and A. Mészáros[§]

**Department of Physics, Bolyai Military University, Budapest, Box-12, H-1456, Hungary*

†Stockholm Observatory, AlbaNova, SE-106 91 Stockholm, Sweden

***Konkoly Observatory, Budapest, Box-67, H-1525, Hungary*

‡Laboratory for Information Technology, Eötvös University, Budapest, Pázmány P. s. 1/A., H-1117, Hungary

§Astronomical Institute of the Charles University, V Holešovičkách 2, CZ 180 00 Prague 8, Czech Republic

Abstract. Gamma-ray bursts can be divided into three groups ("short", "intermediate", "long") with respect to their durations. The third type of gamma-ray bursts - as known - has the intermediate duration. We show that the intermediate group is the softest one. An anticorrelation between the hardness and the duration is found for this subclass in contrast to the short and long groups.

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TWO-DIMENSIONAL GAUSSIAN FITS

Simultaneously Mukherjee et al. [1] and Horváth [2] found a third group of gamma-ray bursts (GRBs). Somewhat later several authors [3, 4, 5, 6] also suggested the existence of the third ("intermediate") group as well. The physical existence of the third group is, however, still not convincingly proven. For example, Hakkila et al. [3] believe that the third group is only a deviation caused by a complicated instrumental effect, which can reduce the durations of some faint long bursts. Later Hakkila et al. [7] published another paper which had different conclusions.

Using Principal Component Analysis (PCA), Bagoly et al. [8] have shown that there are only two major quantities necessary (called the Principal Components; PCs) to characterize most of the properties of the bursts in the BATSE Catalog. Consequently, the problem of the choice of the relevant parameters describing GRBs is basically a two-dimensional problem. For the statistical analysis the choice of two independent parameters is enough; they may be, but are not necessarily, the two principal components. This means that only two parameters, relevantly chosen, should be enough for the classification and determination of the groups. Here we have chosen **duration** T_{90} and **hardness** $H_{32} = F_3/F_2$ (F_3 and F_2 are the fluences) for these parameters.

We can assume that the observed probability distribution of GRBs in this plane is a superposition of the distributions characterizing the different types of bursts present in the sample. Introducing the notations $x = \log T_{90}$ and $y = \log H_{32}$ and using the law of

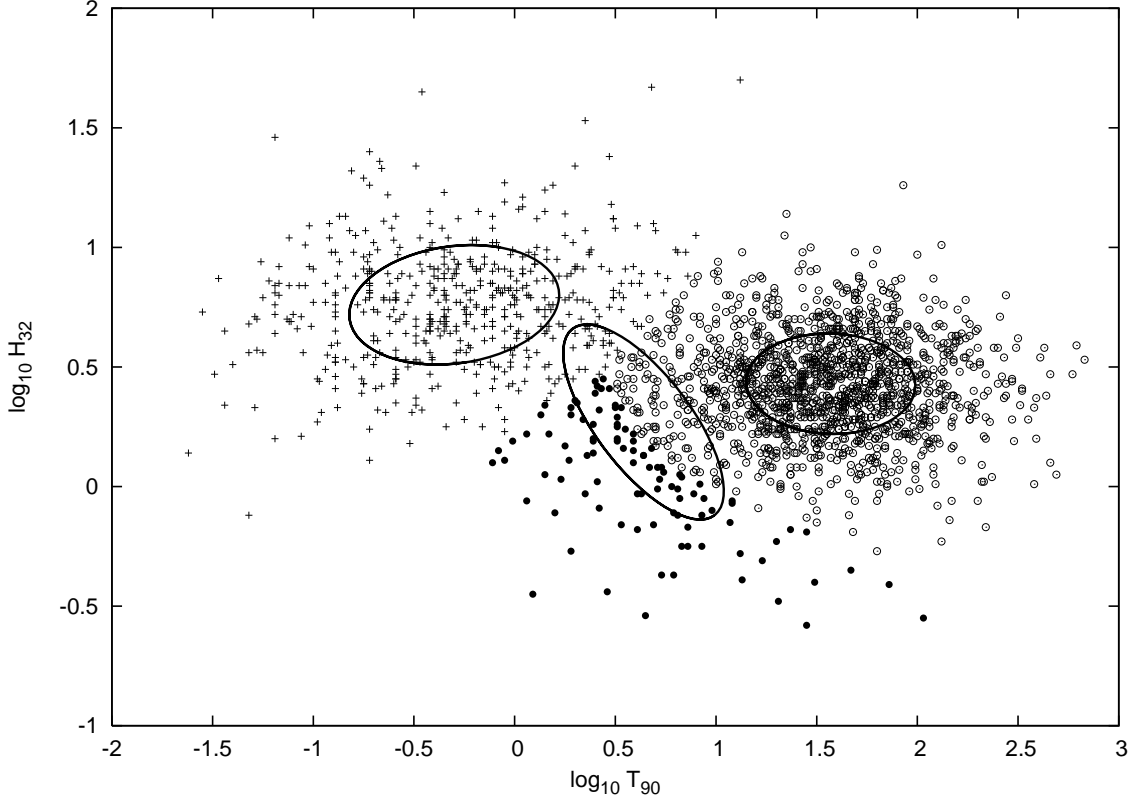


FIGURE 1. The 1956 GRBs in the $\{\log T_{90}; \log H_{32}\}$ plane. The 1σ ellipses of the three Gaussian distributions are also shown, which were obtained in the ML procedure. The different symbols (crosses, filled circles and open circles) mark bursts belonging to the short, intermediate and long classes, respectively.

full probabilities we can write

$$p(x, y) = \sum_{l=1}^k p(x, y|l) p_l. \quad (1)$$

In this equation $p(x, y|l)$ is the conditional probability density assuming that a burst belongs to the l -th class. p_l is the probability for this class in the observed sample, where k is the number of classes. In order to decompose the observed probability distribution $p(x, y)$ into the superposition of different classes we need the functional form of $p(x, y|l)$. The probability distribution of the logarithm of durations can be well fitted by Gaussian distributions, if we restrict ourselves to the short and long GRBs, respectively [9]. We assume the same for the y coordinate as well. Therefore it holds

$$p(x, y|l) = \frac{(1-r^2)^{-\frac{1}{2}}}{2\pi\sigma_x\sigma_y} \exp \left[-\frac{1}{2(1-r^2)} \left(\frac{(x-a_x)^2}{\sigma_x^2} + \frac{(y-a_y)^2}{\sigma_y^2} - \frac{2r(x-a_x)(y-a_y)}{\sigma_x\sigma_y} \right) \right] \quad (2)$$

The observational data from the Current BATSE GRB Catalog will be used. There are 2702 GRBs, for **1956** of which both the hardnesses and durations are measured.

TABLE 1. Parameters of the Gaussian fits ($k = 3$) in the $\{\log T_{90}; \log H_{32}\}$ plane.

| classes | p_l | $a_x = \log T_{90}$ | $a_y = \log H_{32}$ | σ_x | σ_y | r (corr.coef.) |
|---------|-------|---------------------|---------------------|------------|------------|-----------------------|
| 1 | .245 | -.301 | .763 | .525 | .251 | .163 |
| 2 | .109 | .637 | .269 | .474 | .344 | -.513 |
| 3 | .646 | 1.565 | .427 | .416 | .210 | -.034 |

In order to find the unknown constants in Eq.(2) we use the Maximum Likelihood (ML) procedure of parameter estimation [10]. One can define the Likelihood Function in the usual way, after fixing the value of k , in the form $L = \sum \log p(x_i, y_i)$, where $p(x_i, y_i)$ has the form given by Eq.(1). Similarly, as it was done by Balázs et al. [10], the EM (Expectation and Maximization) algorithm is used to obtain the $a_x, a_y, \sigma_x, \sigma_y, r$ and p_l parameters at which L reaches its maximum value. We made the calculations for different values of k in order to see the improvement of L as we increase the number of parameters to be estimated.

The confidence interval of the parameters came from $2(L_{max} - L_0) = \chi_m^2$ equation. Moving from $k=2$ to 3 the number of parameters m increases by 6 (from 11 to 17), and L_{max} grows from 1193 to 1237, which means a very low probability of being a chance (10^{-10}).

Moving from $k=3$ to 4, the improvement in L_{max} is only 6 (from 1237 to 1243), which can happen by chance with a probability of 6.2%. Hence, the inclusion of the fourth class is not justified. Table 1. shows the parameters of the best fit with $k=3$.

RESULTS

The mathematical deconvolution of the $p(x, y)$ joint probability density of the observed quantities into Gaussian components does not necessarily mean that the physics behind the classes obtained mathematically is different. It could well be possible that the true functional form of the distributions is not exactly Gaussian and that the algorithm of deconvolution formally inserts a third one only in order to get a satisfactory fit. One needs detailed investigations based on the physical (e.g. spectral) properties of the individual bursts to prove its astrophysical validity.

Norris et al. [11] and Balázs et al. [10] found compelling evidence that there is a significant difference between the short and long GRBs. This might indicate that different types of engines are at work. The relationship of long GRBs to the massive collapsing objects is now also observationally well established, and the relation between the comoving and observed time scales is well understood [12, 13]. The short bursts can be identified as originating from neutron star (or black hole) mergers. Therefore the mathematical classification of GRBs into the short and long classes is physically justified.

An important question that must be answered in this context is whether the intermediate group of GRBs, obtained in the previous paragraph from the mathematical classification, really represents a third type of burst physically different from both the short and the long ones.

The classification into the short, intermediate and long classes is based mainly on the duration of the burst. From Table 1 one may infer that these three classes differ also in the hardnesses. The difference in the hardnesses between the short and long group is well known [14]. According to these data the **intermediate** GRBs are the **softest** among the three classes. This different small mean hardness and also the different average duration suggest that the intermediate group should also be a different phenomenon, that is, both in hardness and in duration the third group differs from the other two. On the other hand, no significant correlation exists between the hardness and the duration within the short and the long classes. Thus, these two quantities may be taken as two independent variables, and the short and long groups are different in both these independent variables.

In contrast, there is a strong **anticorrelation** between the hardness and the duration within the intermediate class. This is a surprising, new result, and because the hardness and the duration are not independent in the third group, one may simply say that only one significant physical quantity is responsible for the hardness and the duration within the intermediate group. Consequently, the situation is quite different here, because one needs two independent variables to describe the remaining two other groups. This is a strong constraint in modeling the third group. Hence, the question of the true nature of the physics in the intermediate group remains open, and needs further analysis.

In this paper we have shown that statistically a third group of GRBs exists. Also statistically no further groups are needed to describe the $\{\log T_{90}; \log H_{32}\}$ distribution of bursts. Finally, 11% of GRBs in the Current BATSE Catalog belong to the intermediate class. The memberships of the cataloged bursts are available on the internet [15].

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REFERENCES

1. Mukherjee, S., et al. 1998, ApJ, 508, 314
2. Horváth, I. 1998, ApJ, 508, 757
3. Hakkila, J., et al. 2000, ApJ, 538, 165
4. Balastegui, A., Ruiz-Lapuente, P., & Canal, R. 2001, MNRAS, 328, 283
5. Rajaniemi, H.J., & Mähönen, P. 2002, ApJ, 566, 202
6. Horváth, I., et al. 2006, A&A, in print
7. Hakkila, J., et al. 2003, ApJ, 582, 320
8. Bagoly, Z., Mészáros, A., Horváth, I., Balázs, L.G., & Mészáros, P. 1998, ApJ, 498, 342
9. Horváth, I. 2002, A&A, 392, 791
10. Balázs, L.G., Bagoly, Z., Horváth, I., Mészáros, A., & Mészáros, P. 2003, A&A, 138, 417
11. Norris, J.P., Scargle, J.D., & Bonnell, J.T. 2001, Gamma-Ray Bursts in the Afterglow Era, Proc. Int. Workshop held in Rome, Italy, eds. E. Costa et al., ESO Astrophysics Symp. (Berlin: Springer), p. 40
12. Fox, D.B., et al. 2005, Nature, 437, 845
13. Ryde, F., & Petrosian, V. 2002, ApJ, 578, 290
14. Kouveliotou, C., et al. 1993, ApJ, 413, L101
15. Horváth, I., et al. 2005, class memberships <http://itl7.elte.hu/~hoi/grb/class.html>